



Fatigue analysis of seam welds in lightweight aluminum structures

ECS Simulation Conference 2023

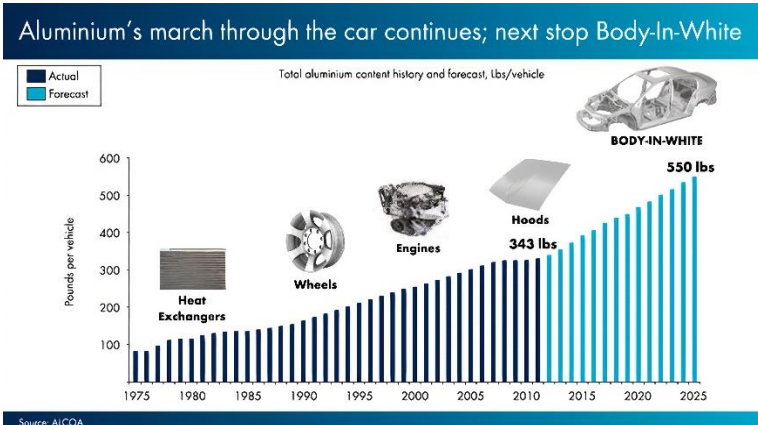
May 10th – 11th, Linz

Mislav Vukić, [Roman Baranja](#), Dr. Richard Tichy, Harald Pramberger
MSc. Thesis: Mislav Vukić

Content

- Introduction and motivation
- Considered fatigue life assessment methods
- Fatigue life assessment with *FEMFAT Weld*
- Experimental setup and procedure
- Calibration procedure
- The results
- Conclusions

Introduction and motivation



Rise in aluminum content per vehicle over the years [1]

Audi R8 Spyder V10

Audi Space Frame in Multimaterialbauweise
Audi space frame in multimaterial construction

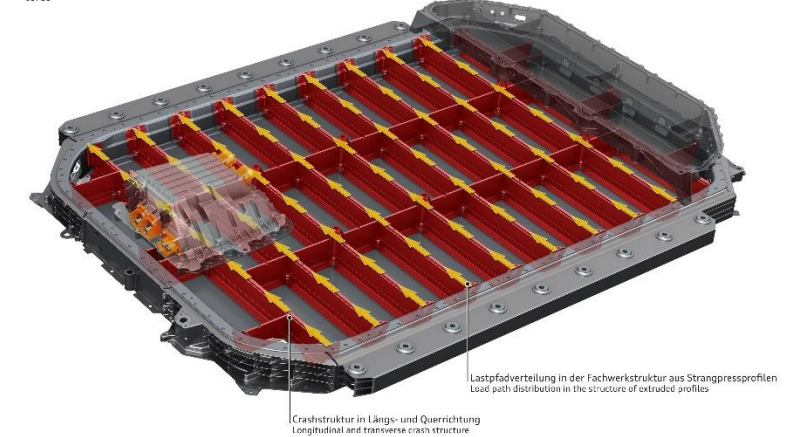
- Kohlenstofffaserverstärkter Kunststoff (CFK)
Carbon fiber-reinforced plastic (CFRP)
- Aluminium-Profil
Aluminum section
- Aluminium-Blech
Aluminum sheet
- Aluminium-Guss
Aluminum castings



Space frame of a modern-day vehicle in multi-material construction [2]

Audi e-tron 55 quattro

Integrierte Crashstruktur der Lithium-Ionen-Batterie
Integrated crash structure of the lithium-ion battery



An example of a battery pack with integrated crash structure out of extruded aluminum profiles [3]

[1] Schubert, E.: *Challenges in Thermal Welding of Aluminium Alloys*, World Journal of Engineering and Technology, 2018, 6, 296-303

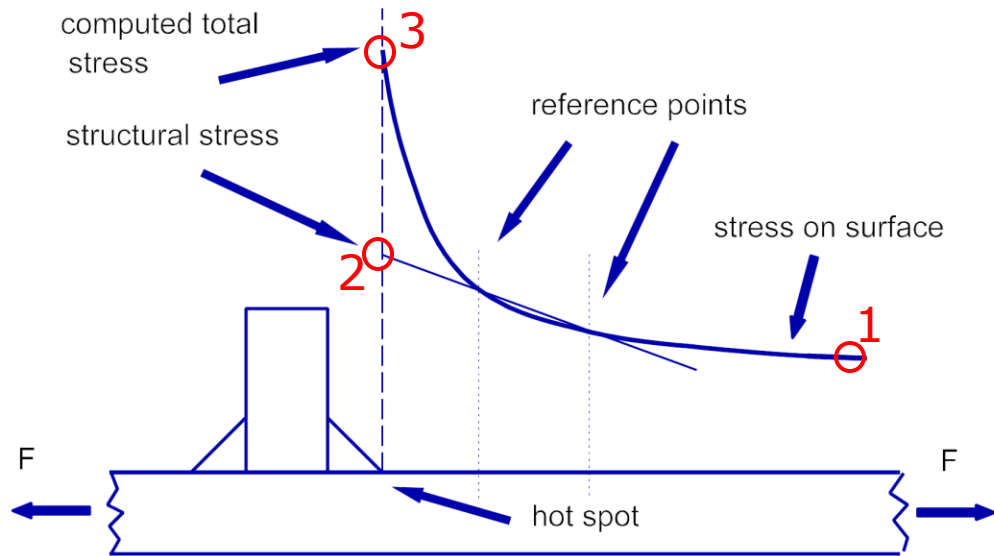
[2] <https://www.audi-mediacycenter.com/en/audi-r8-72>

[3] <https://www.audi-mediacycenter.com/en/audi-e-tron-75>

Content

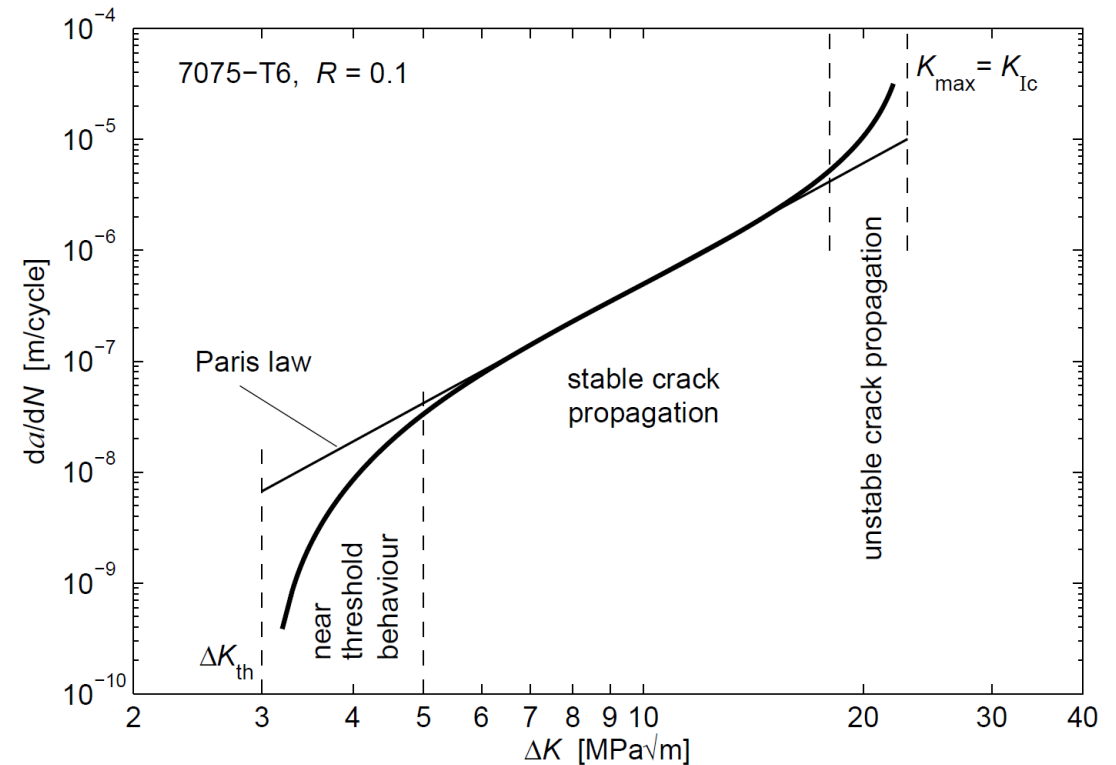
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Considered fatigue life assessment methods



Stress based approaches [4]:

- 1 Nominal stress approach
- 2 Structural hot spot stress approach
- 3 Effective notch stress approach



Crack propagation analysis [5]

[4] IIW: *Recommendations for Fatigue Design of Welded Joints and Components*, International Institute of Welding document IIW-1823-07, 2008

[5] Mann, T.: *Fatigue assessment methods for welded structures and their application to an aluminium T-joint*, Doctoral Thesis, Norwegian University of Science and Technology, 2006

Content

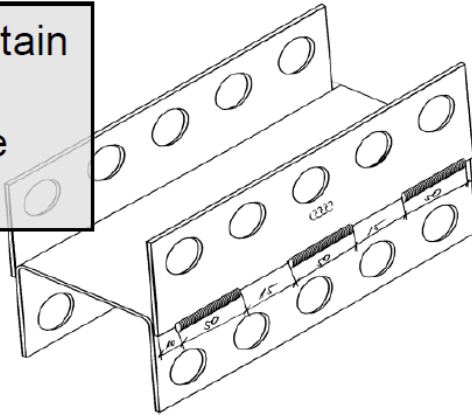
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Fatigue life assessment with *FEMFAT Weld*

Effective notch stress approach

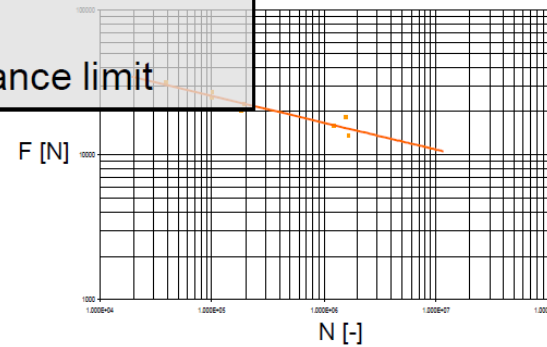
Testing of a certain

- weld joint
- seam shape
- material



S/N curve from test

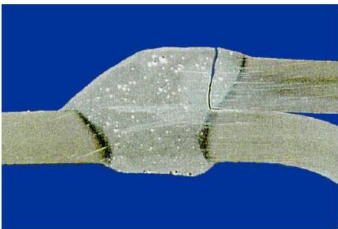
- slope
- endurance limit



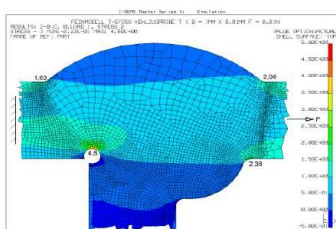
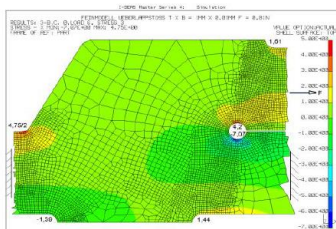
The approach and the process:

- Testing of a certain weld joint, ideally covering all three load cases (tension, bending, power flow)
- Metallographic measurements of the joint section for the fine FE models
- Notch factors extraction

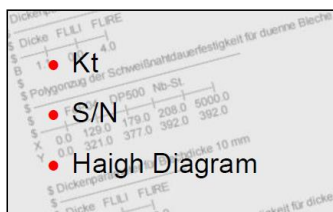
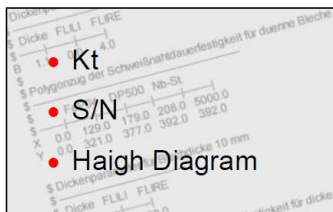
Metallographic section of Specimen



Fine FE Model Radaj Method

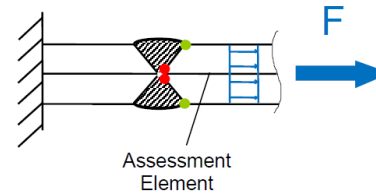


Storing Notch Factors in Database



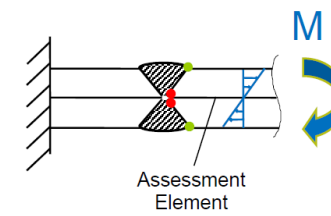
Load Case1

Tensile/Compression



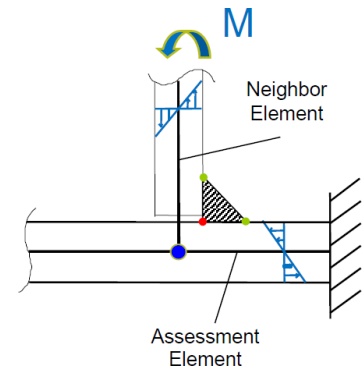
Load Case 2

Bending



Load Case 3

Power flow over neighbour element



... up to 4 assessment points per sheet:

- Transition Area Top and Bottom
- Root Top and Bottom

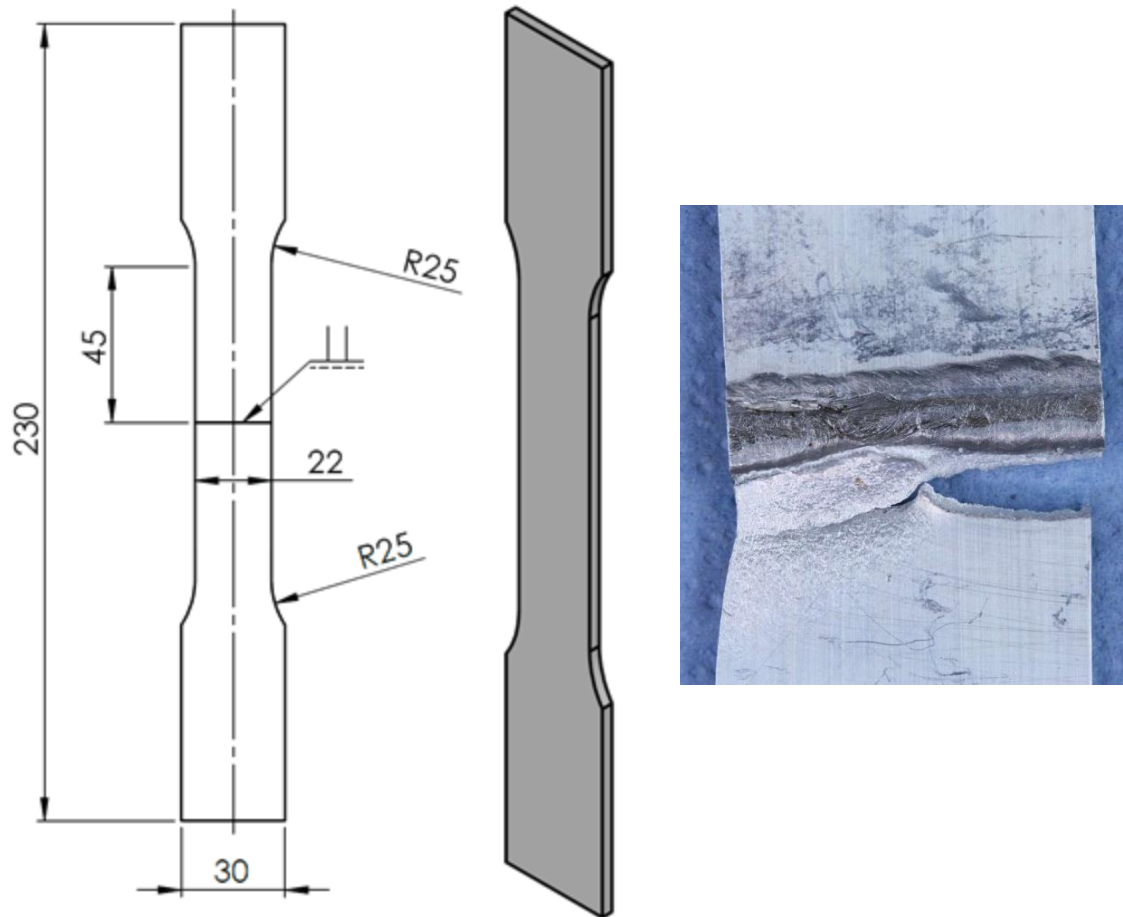
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Experimental procedure

Specimen geometry

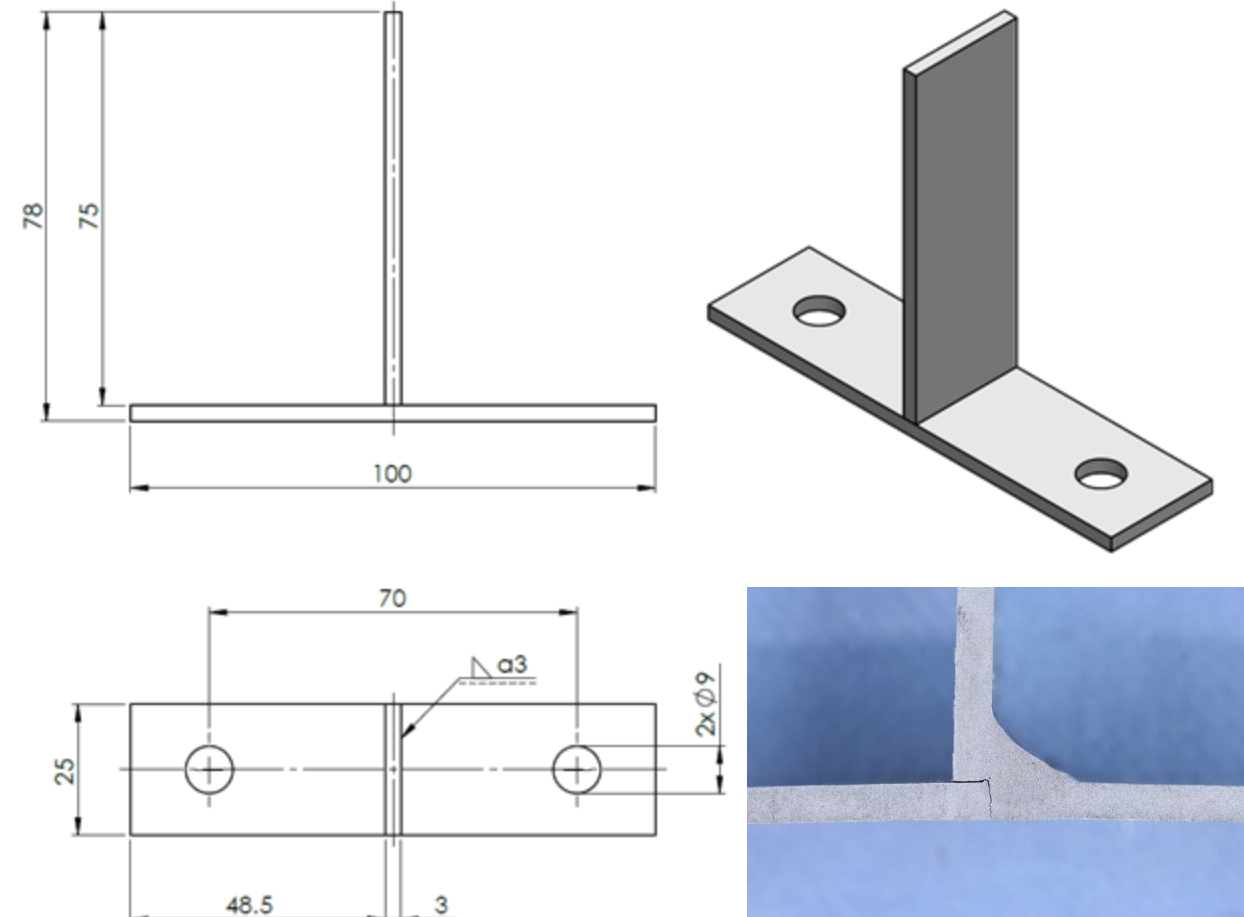
Butt joint welded specimen



Two types of welded specimens were selected:

- I-seam butt joint
- One sided T-joint
- Welding technology: MIG with AlSi5 (4043) filler

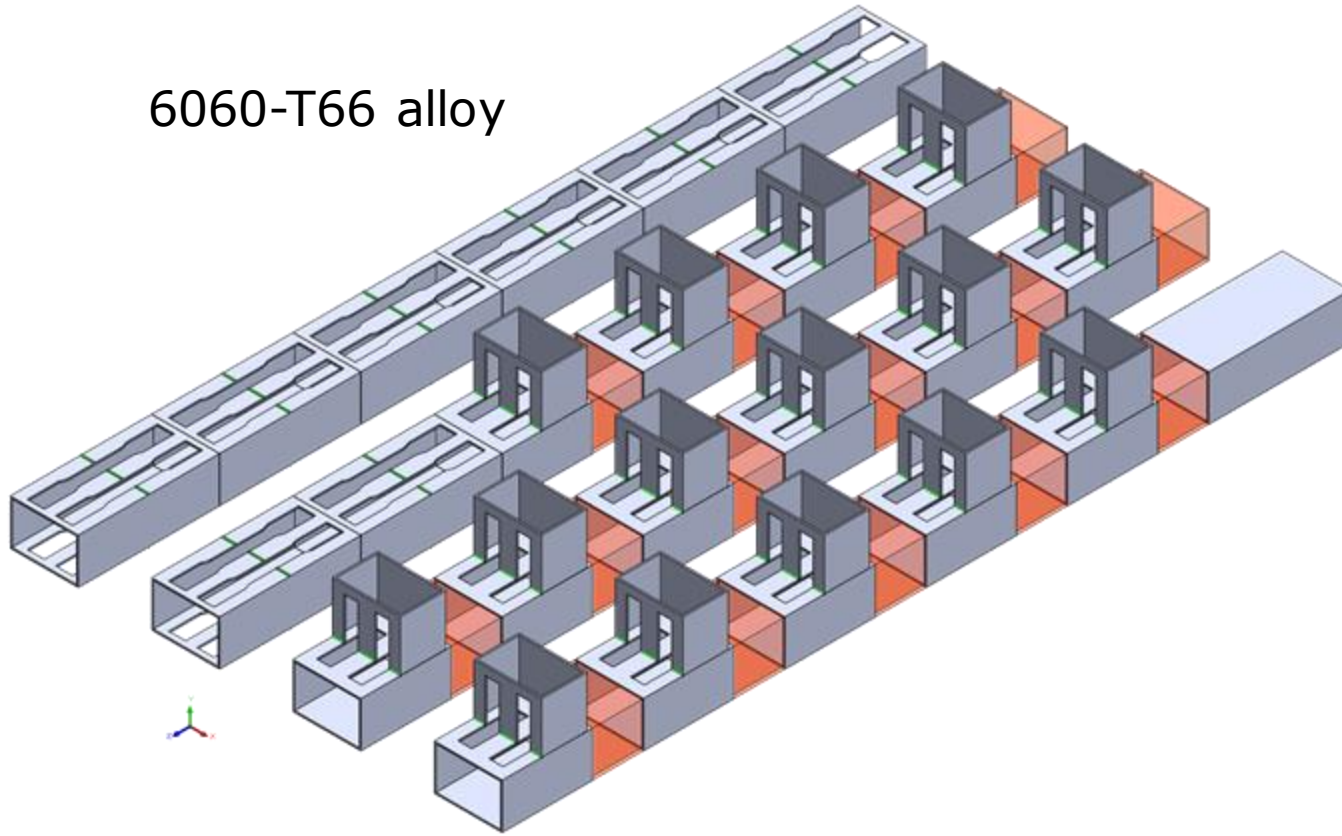
T-joint welded specimen



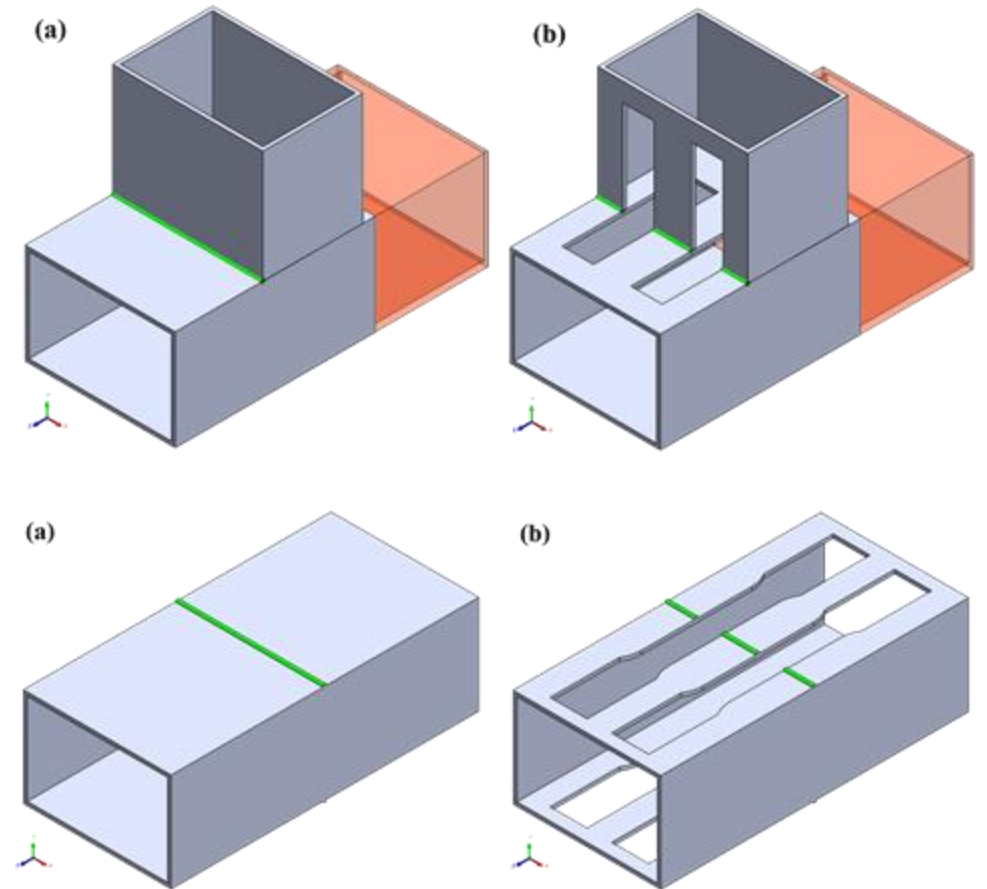
Experimental procedure

Specimen welding and cutting

6060-T66 alloy



- Hollow rectangular profile with 3 mm wall thickness
- Specimens were cut after the welding process, therefore no influence of weld ends is considered



(a) after MIG welding
(b) after EDM cutting

Experimental procedure

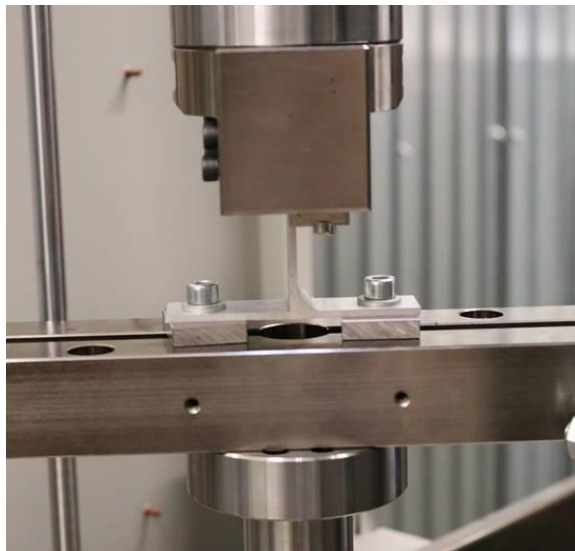
Fatigue testing

- Tension and bending load cases tested, with $R = 0.1$
- 12 tests per load case and specimen
- Crack initiation site (toe / root) inspected

Order	Specimen	Quantity	Test type	Crack initiation point
1	butt joint	12	tension	bottom side weld toe
2	T-joint	12	tension	weld root
3	T-joint	12	3-point bending	weld toe
4	butt joint	12	3-point bending	top side weld toe



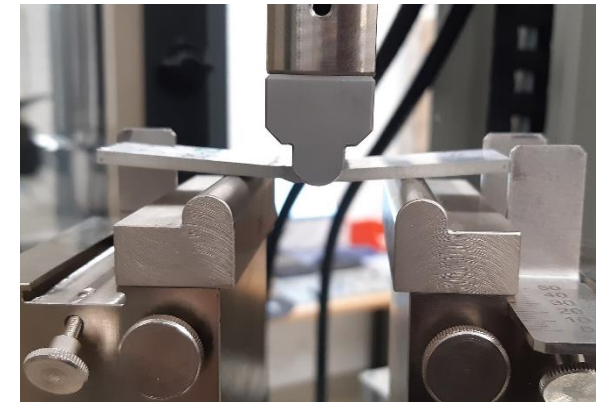
1



2



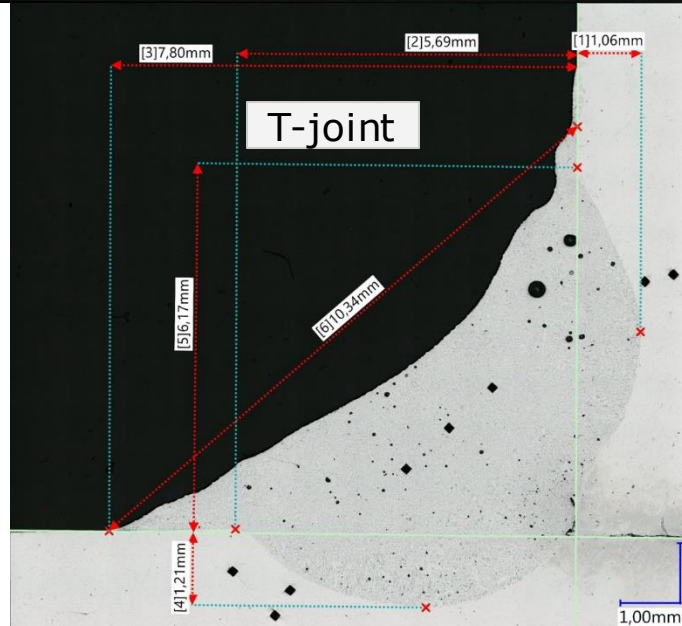
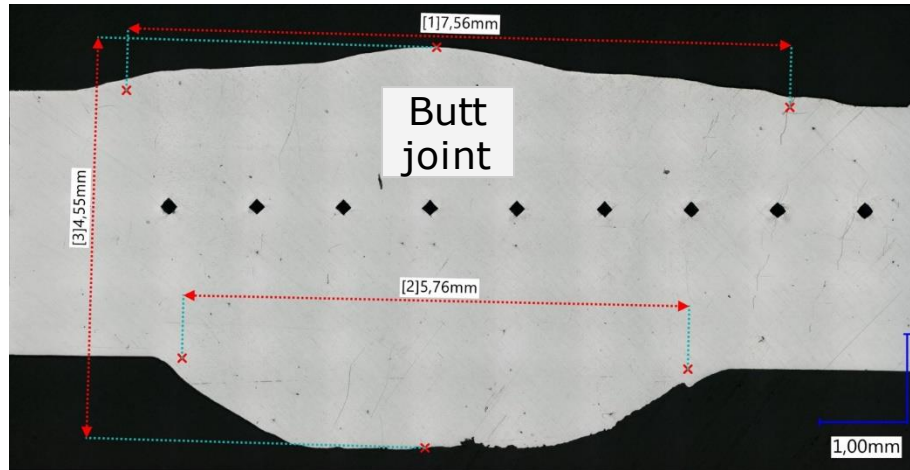
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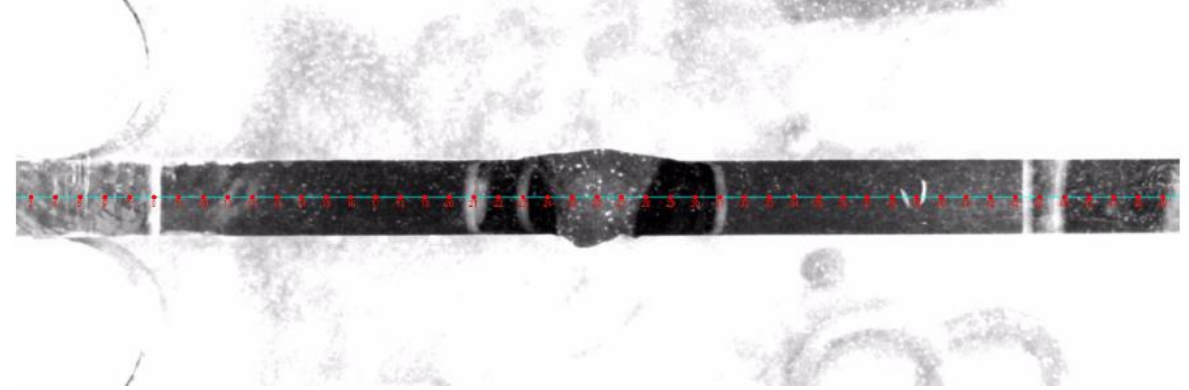
4

Experimental procedure

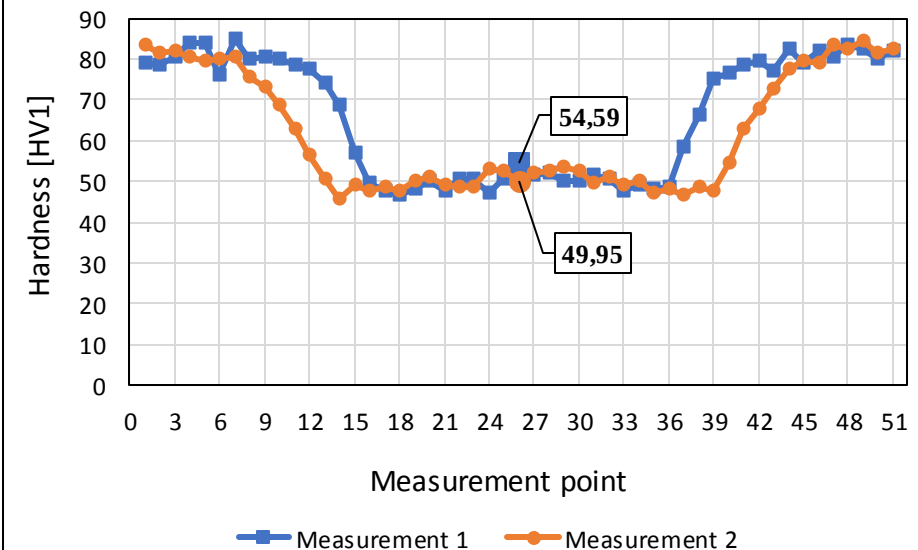
Metallographic measurements



- Microscopy and hardness measurements of the joint section cuts



Hardness measurements of butt joint specimens



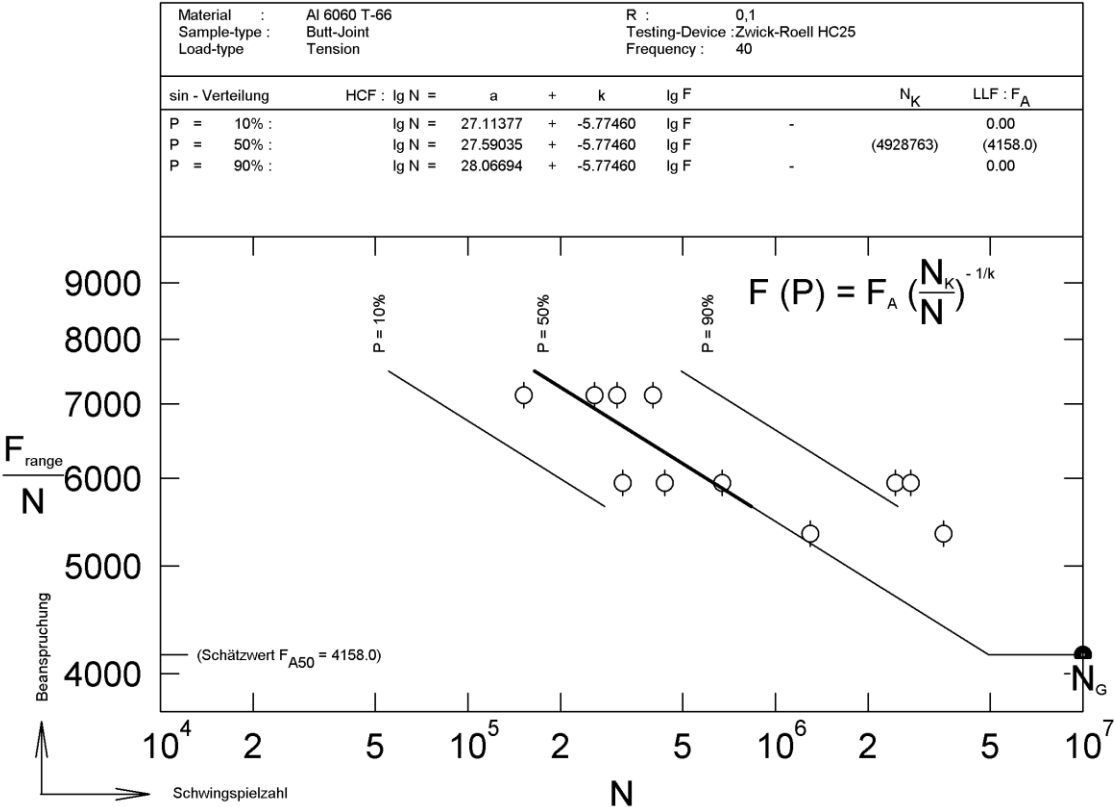
Experimental procedure

Fatigue results @ butt-joint

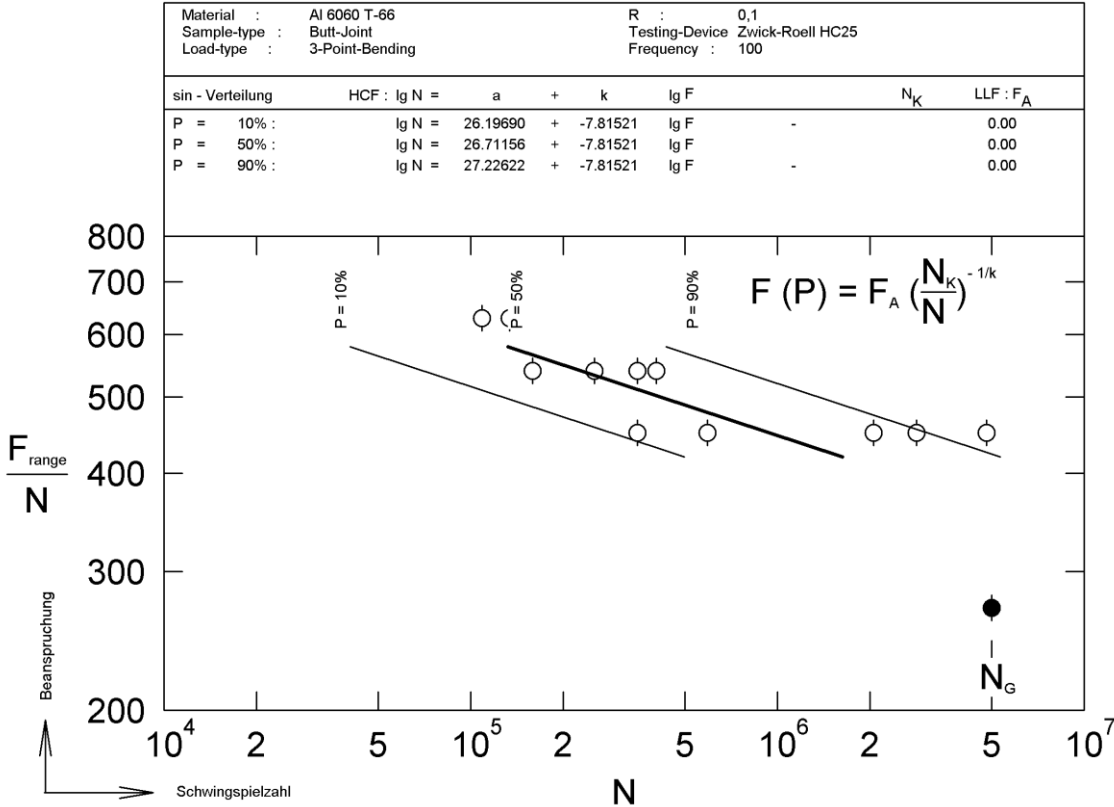
- Testing results given for 10 %, 50 % and 90 % survival probability
- Endurance cycle limit assumed at 2e+06 cycles

	Slope, k	RoD, T _{10/90}
Tension	5.8	1.46
Bending	7.8	1.35

Tension



Bending



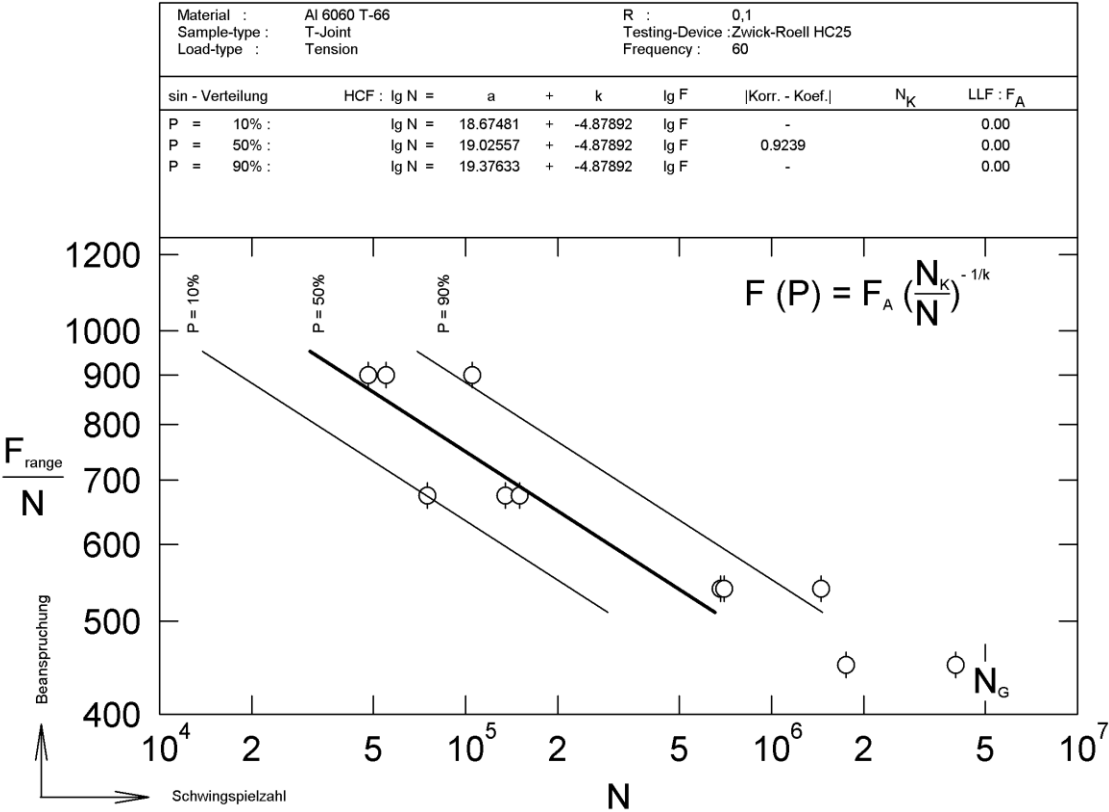
Experimental procedure

Fatigue results @ T-joint

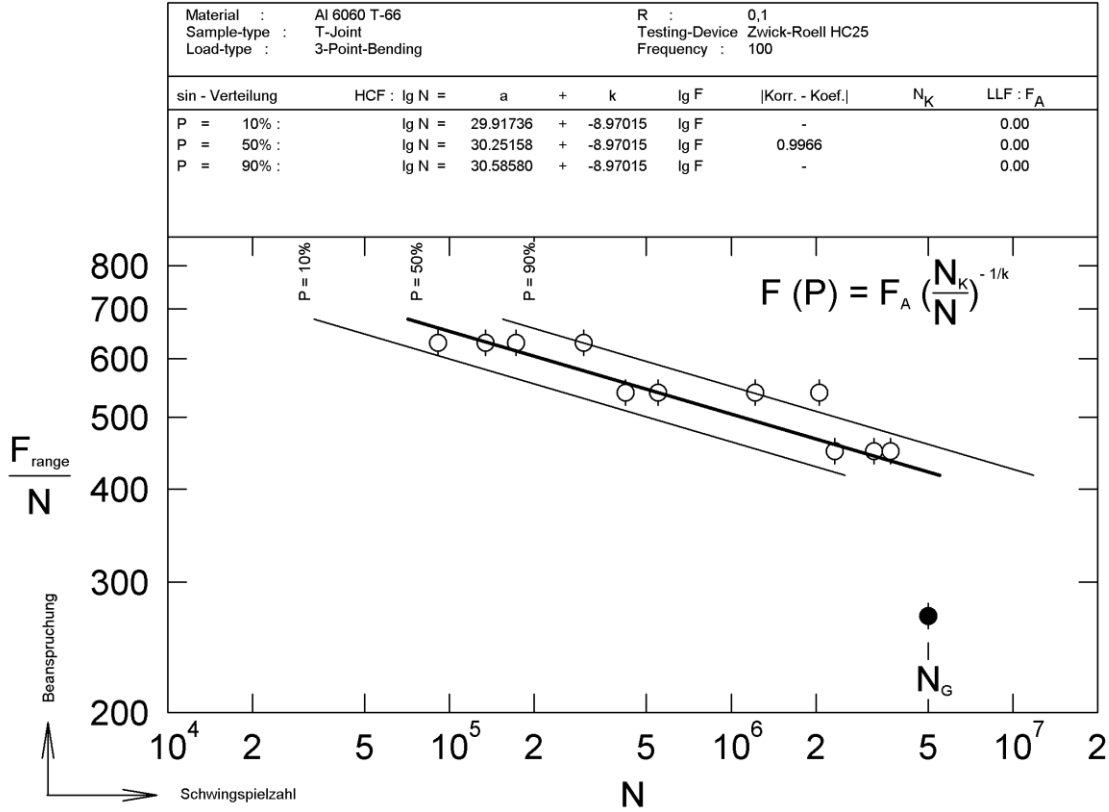
- Testing results given for 10 %, 50 % and 90 % survival probability
- Endurance cycle limit assumed at 2e+06 cycles

	Slope, k	RoD, T _{10/90}
Tension	4.9	1.39
Bending	9.0	1.18

Tension



Bending



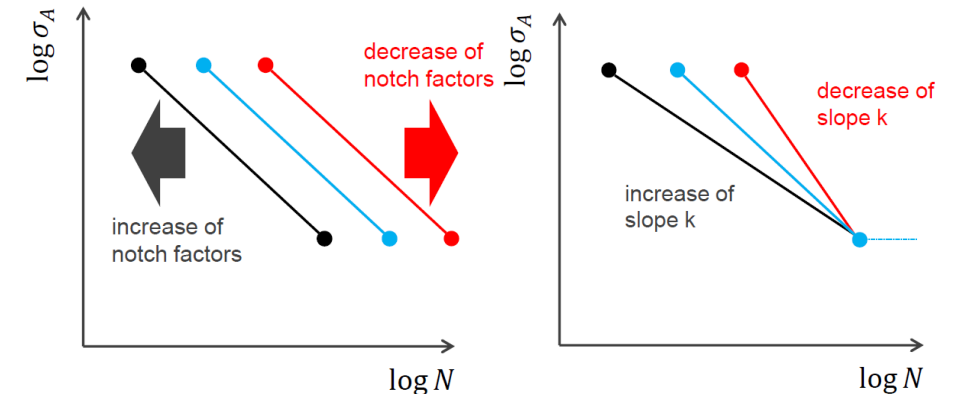
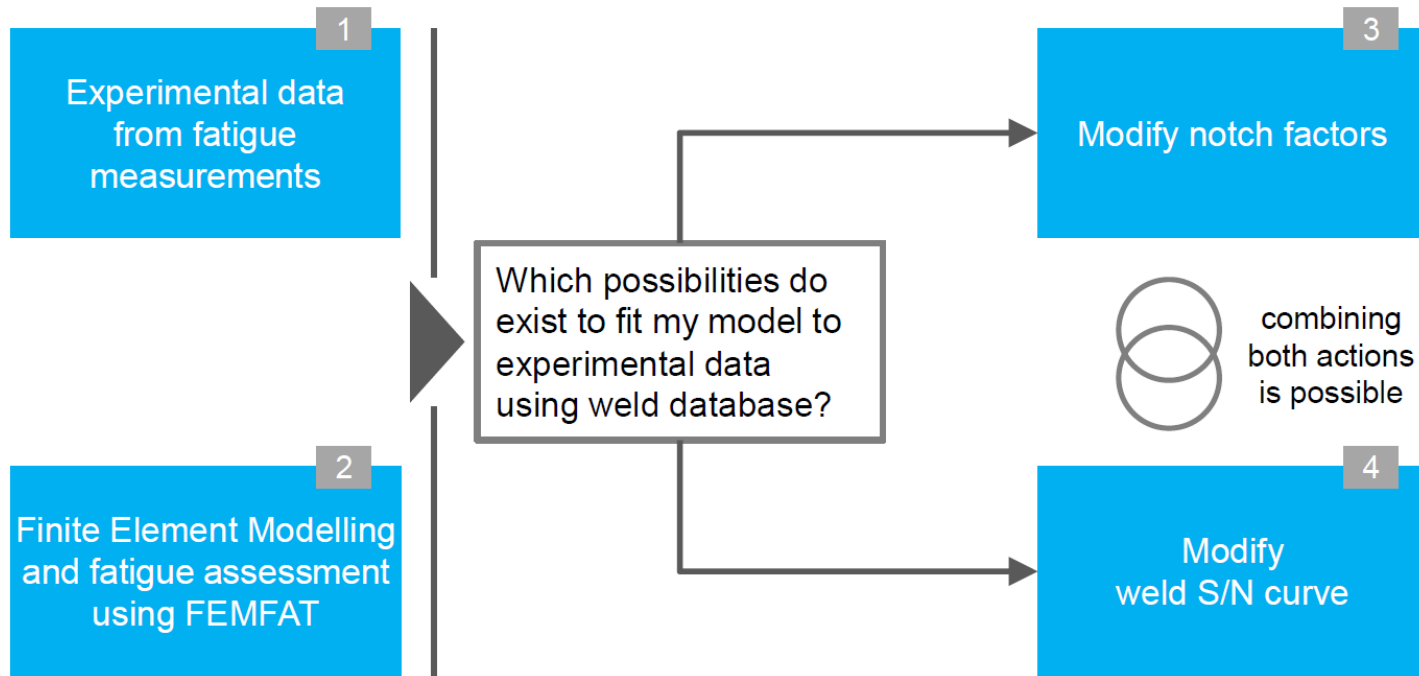
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Calibration procedure

Calibration process:

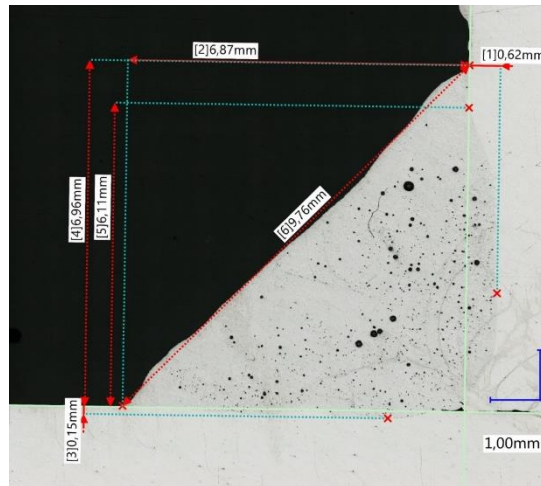
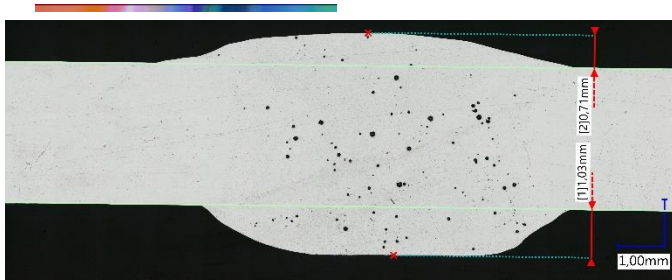
- Finite element modeling for notch factor extraction
- Calibration of notch factors and joint/load-based S/N curve



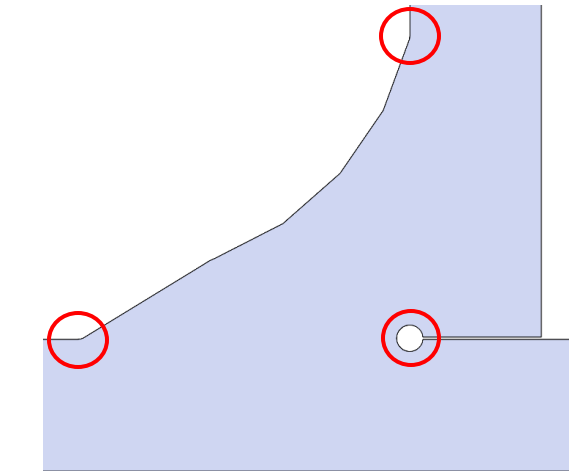
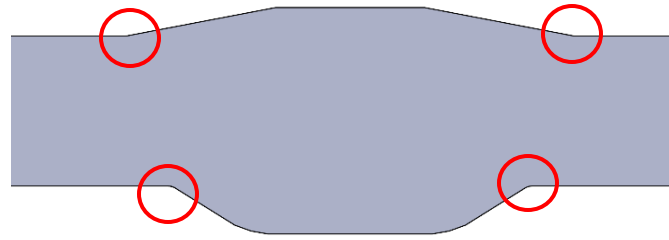
[6] FEMFAT weld - advanced training, March 2021

Calibration procedure

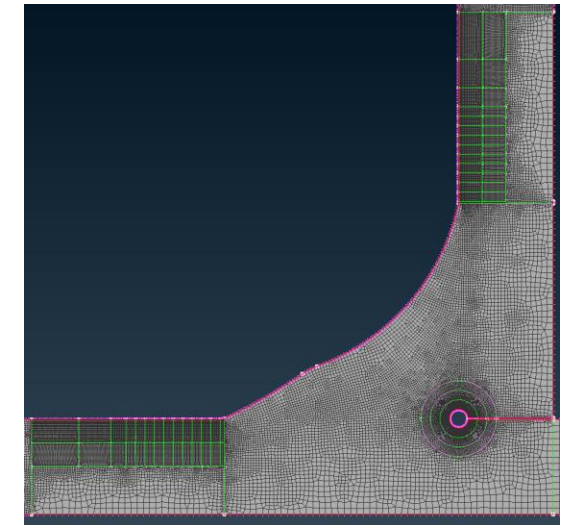
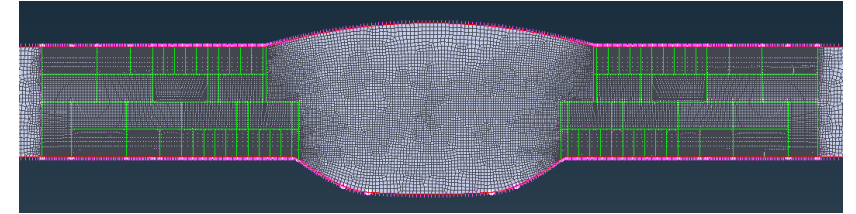
Creation of the FE model with detailed weld geometry



Microscope measurements
of an actual specimen



CAD model based on the
measurements

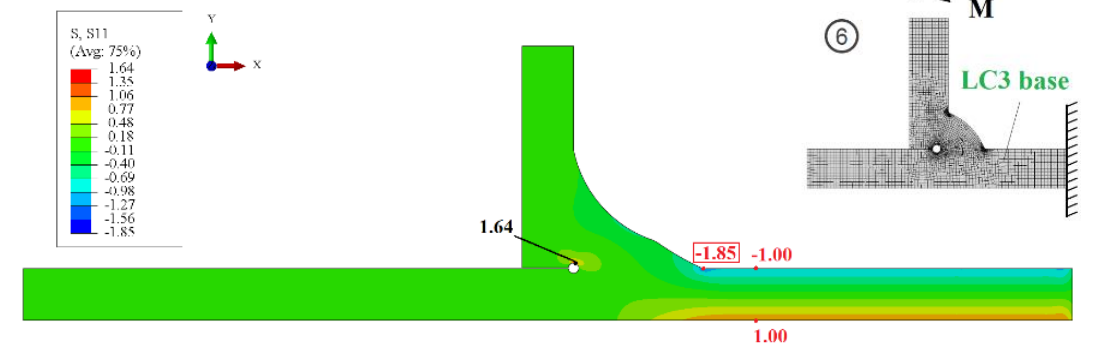
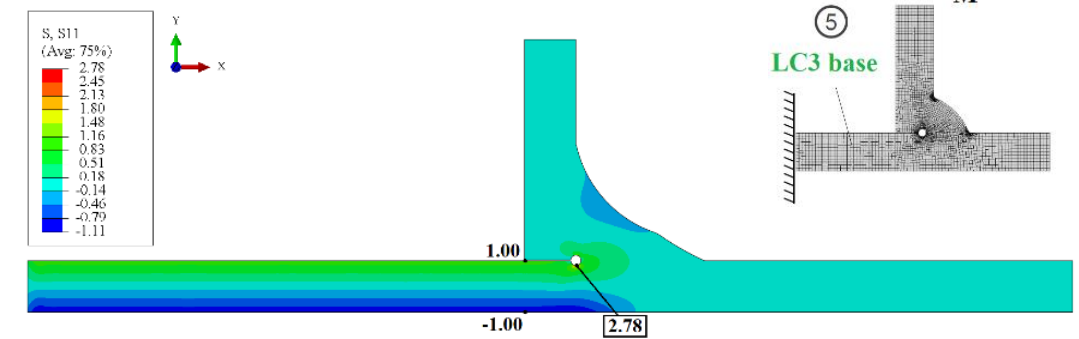
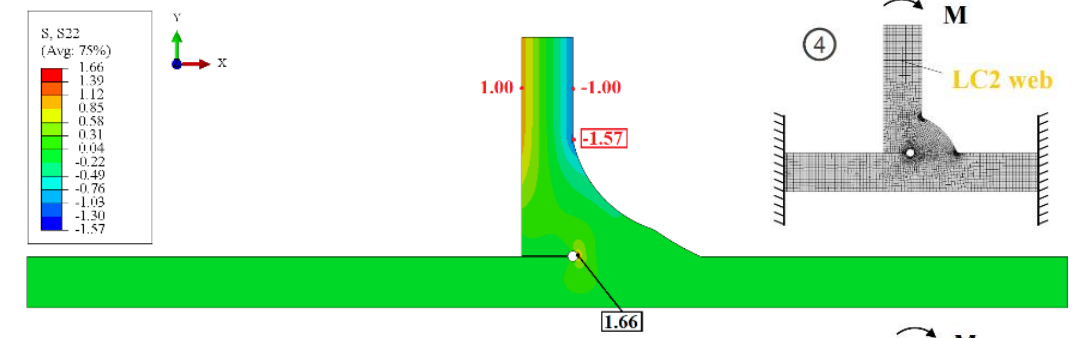
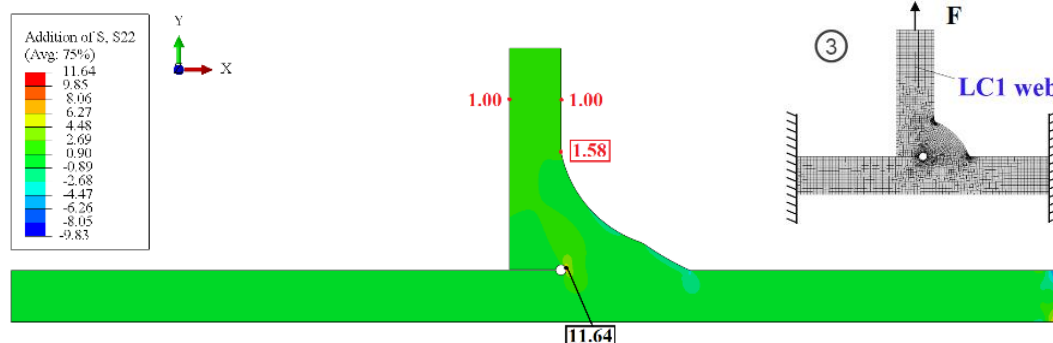
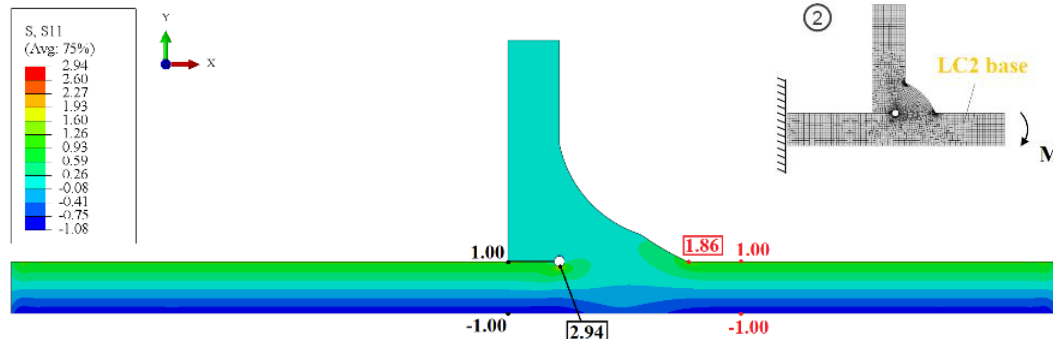
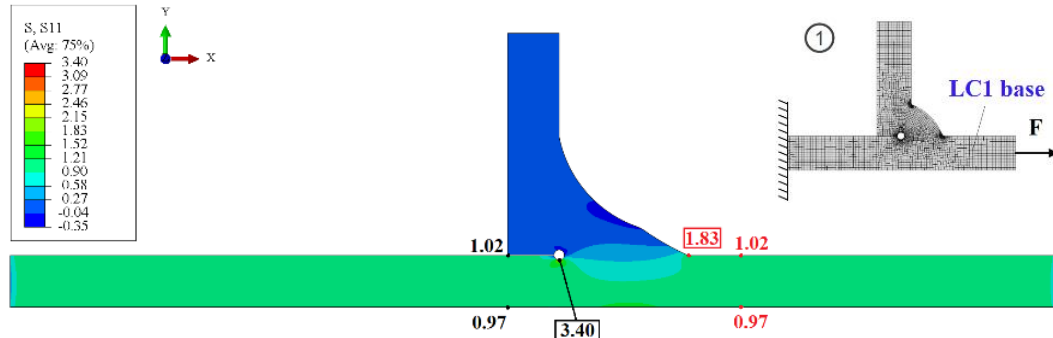


2D shell mesh of the
specimen cross section

- FE model with plane stress elements and ABAQUS solver
- Fictious notch radius assumed as $r = t / 10 = 0.3 \text{ mm}$ according to FEMFAT guidelines for T-joint
- Fictious notch radius assumed as $r = 0.3 \text{ mm}$ and $r = 1.0 \text{ mm}$ for butt joint

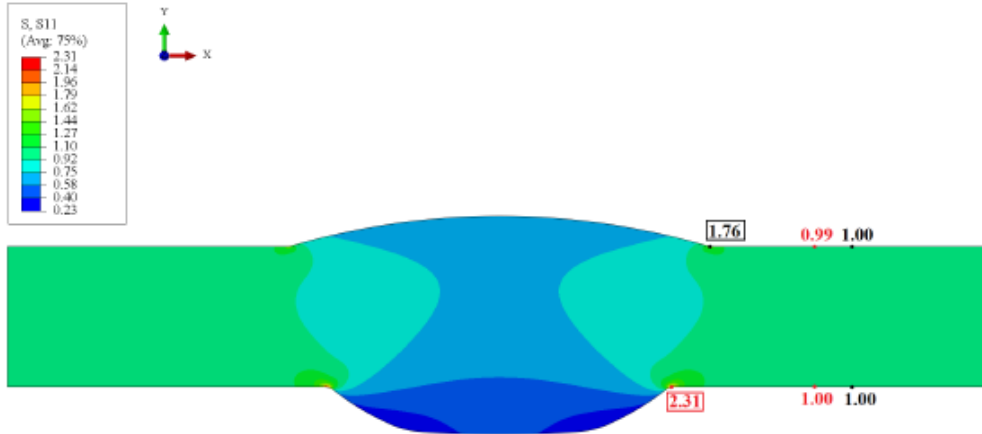
Calibration procedure

Notch factors for T-joint and $r = 0.3 \text{ mm}$

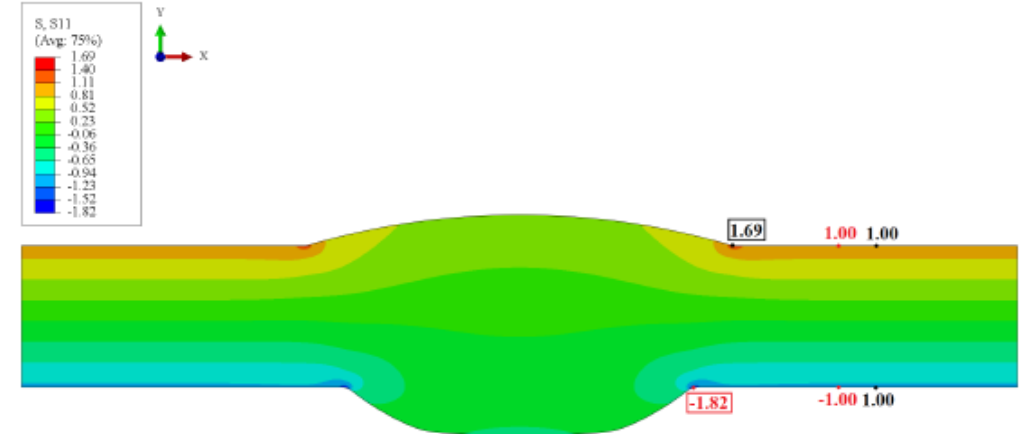


Calibration procedure

Notch factors for Butt-joint, $r = 0.3 \text{ mm}$ and $r = 1.0 \text{ mm}$



stress S11 distribution in the butt joint specimen for lc1



stress S11 distribution in the butt joint specimen for lc2

Calculated notch factors for non-symmetrical I-seam weld with $r = 1.0 \text{ mm}$

	lc1	lc2
Weld toe at the top	1.76	1.69
Weld toe at the bottom	2.31	1.82

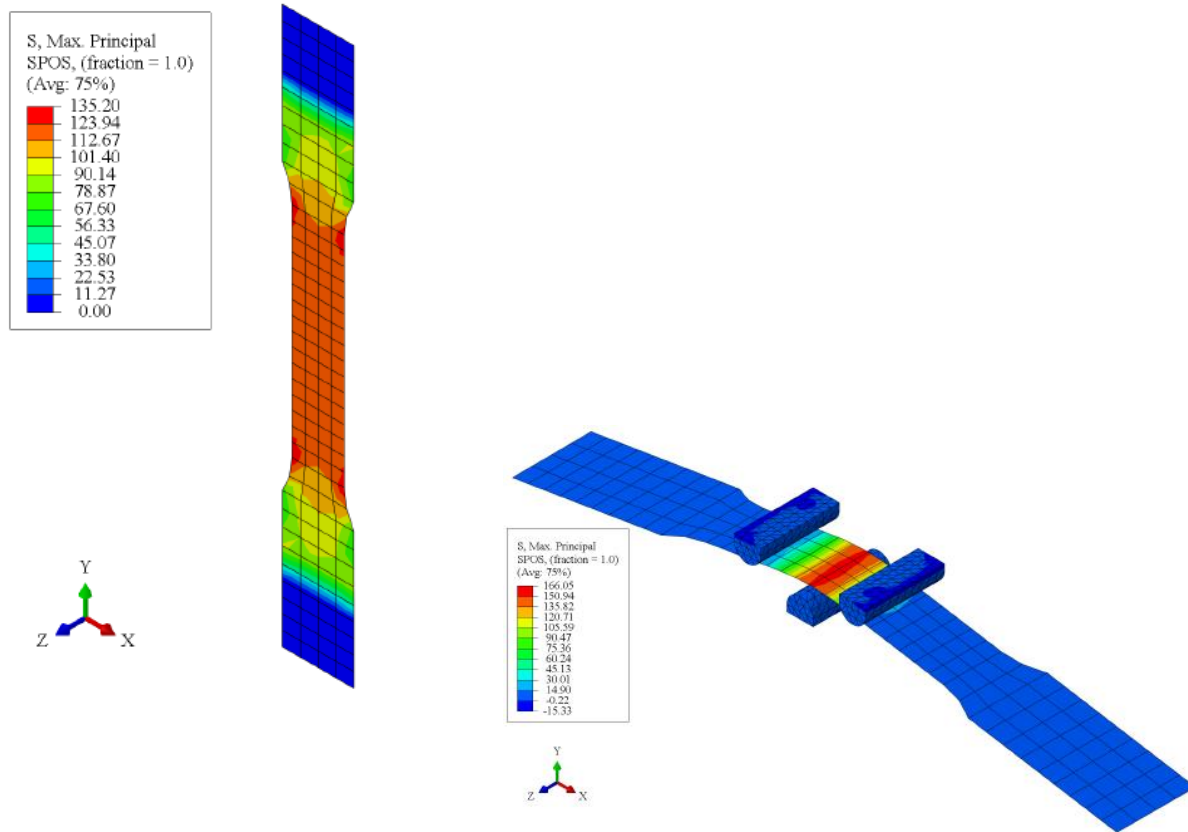
Calculated notch factors for non-symmetrical I-seam weld with $r = 0.3 \text{ mm}$

	lc1	lc2
Weld toe at the top	2.64	2.54
Weld toe at the bottom	3.47	2.73

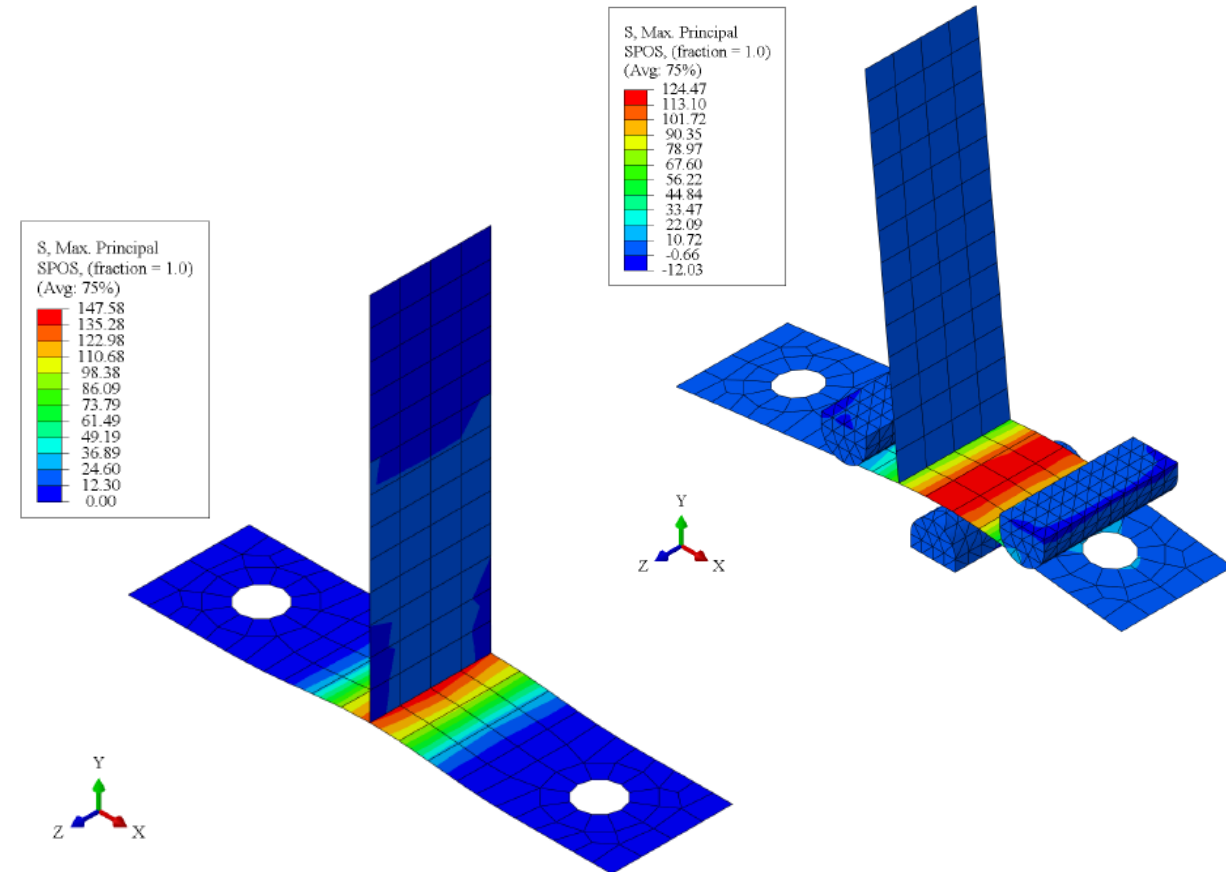
Calibration procedure

General FE models for verification

Butt joint welded specimen



T-joint welded specimen

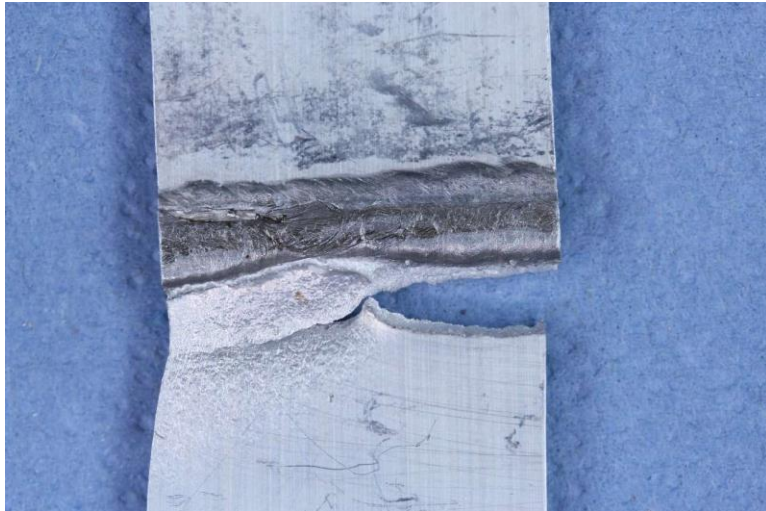


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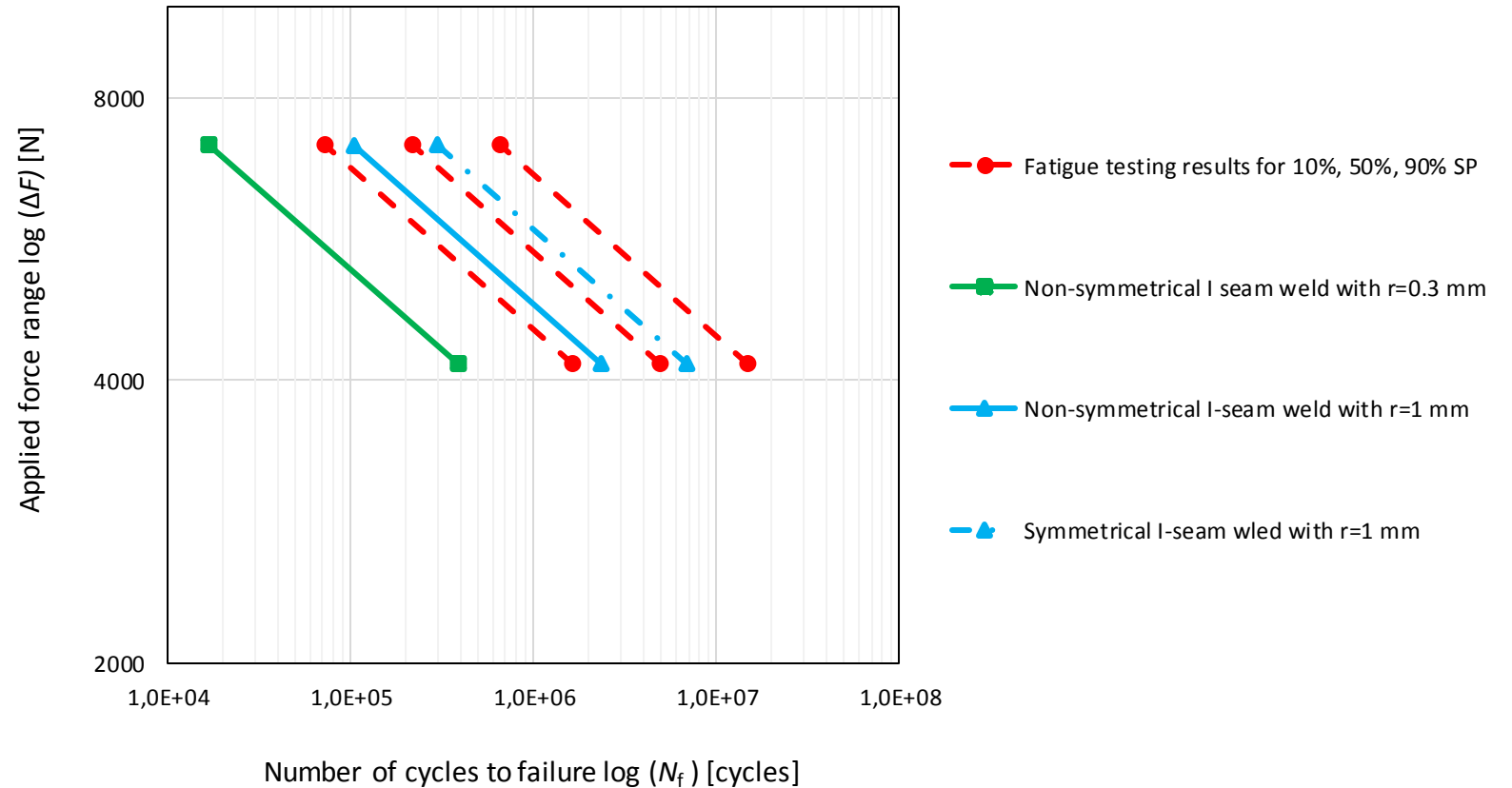
HCF testing and *FEMFAT Weld* results comparison

Butt joint specimen – tension



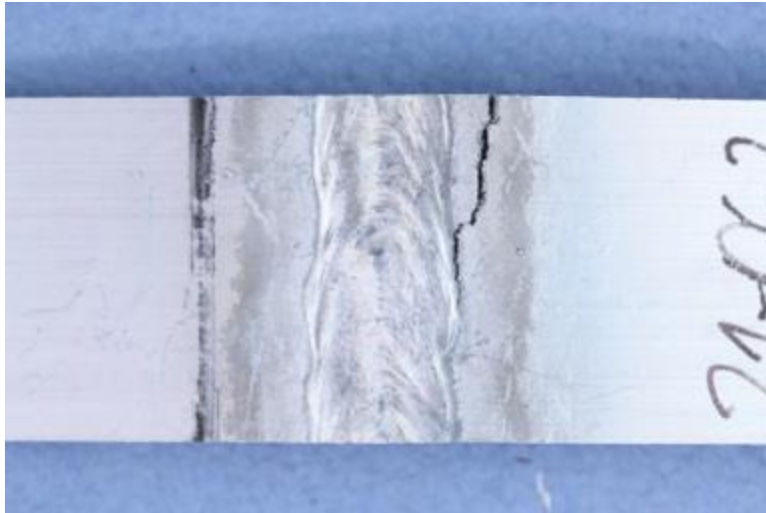
Crack initiation at the bottom side weld toe

- Assumption of $r = 0.3$ mm too conservative
- Good correlation for $r = 1.0$ mm, especially considering symmetric joint (notch factors 1.76 / 1.69)



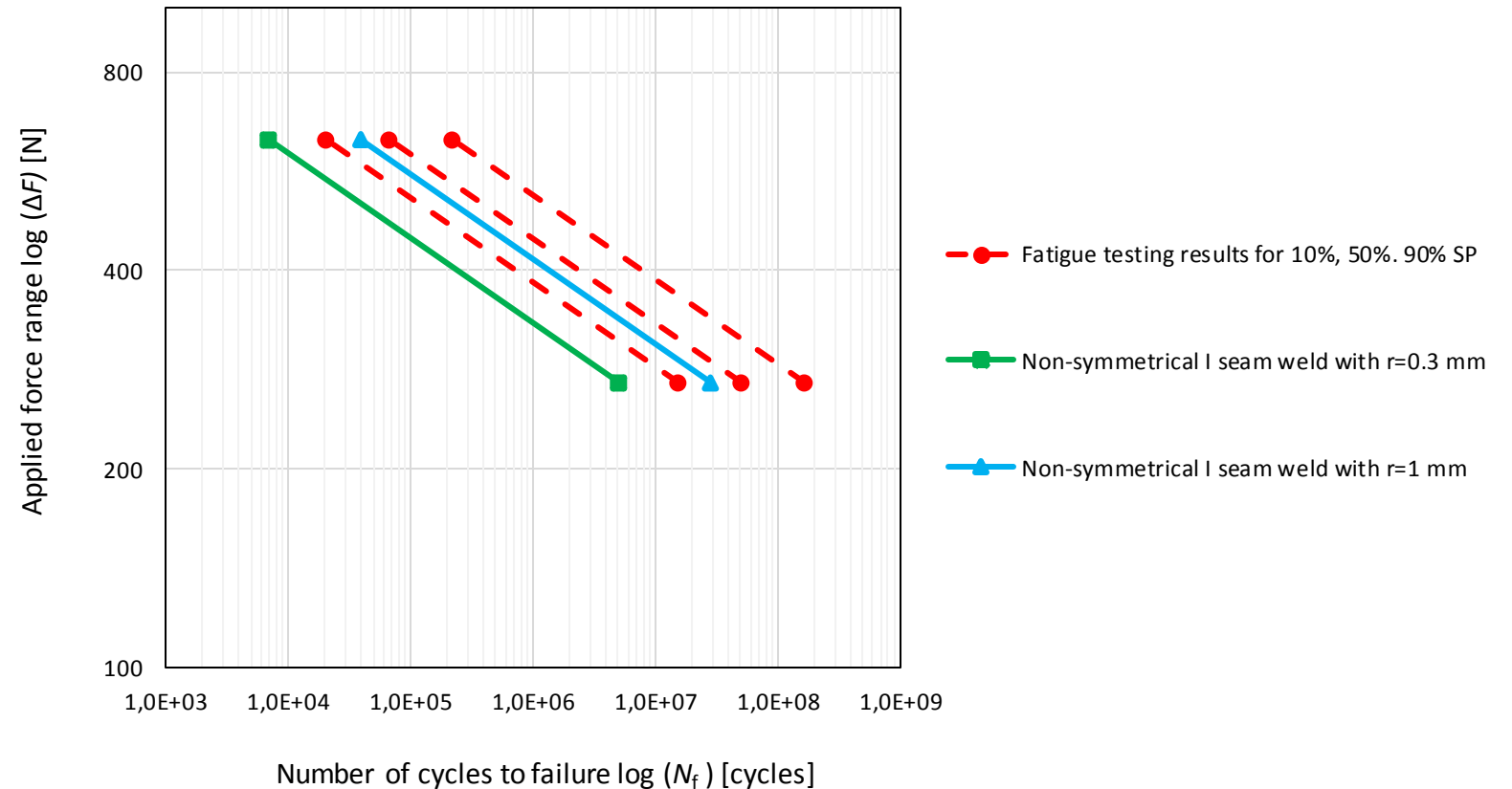
HCF testing and *FEMFAT Weld* results comparison

Butt joint specimen – 3-point bending



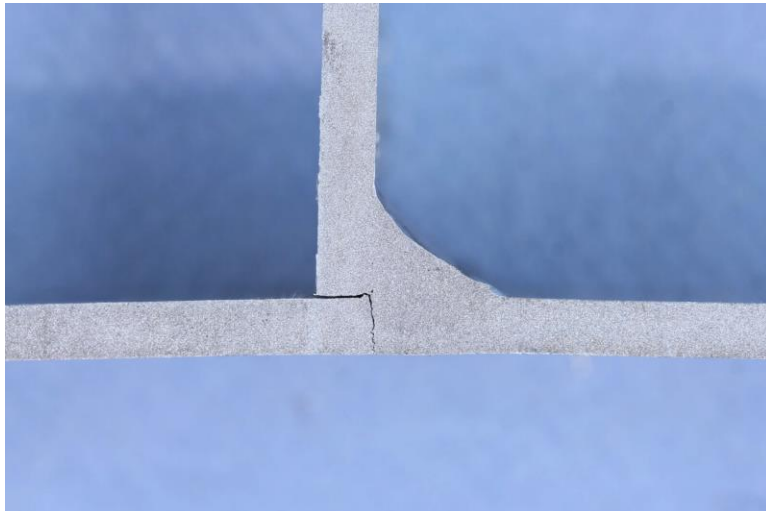
Crack initiation at the top side weld toe

- Assumption of $r = 0.3$ mm too conservative
- Good correlation for $r = 1.0$ mm



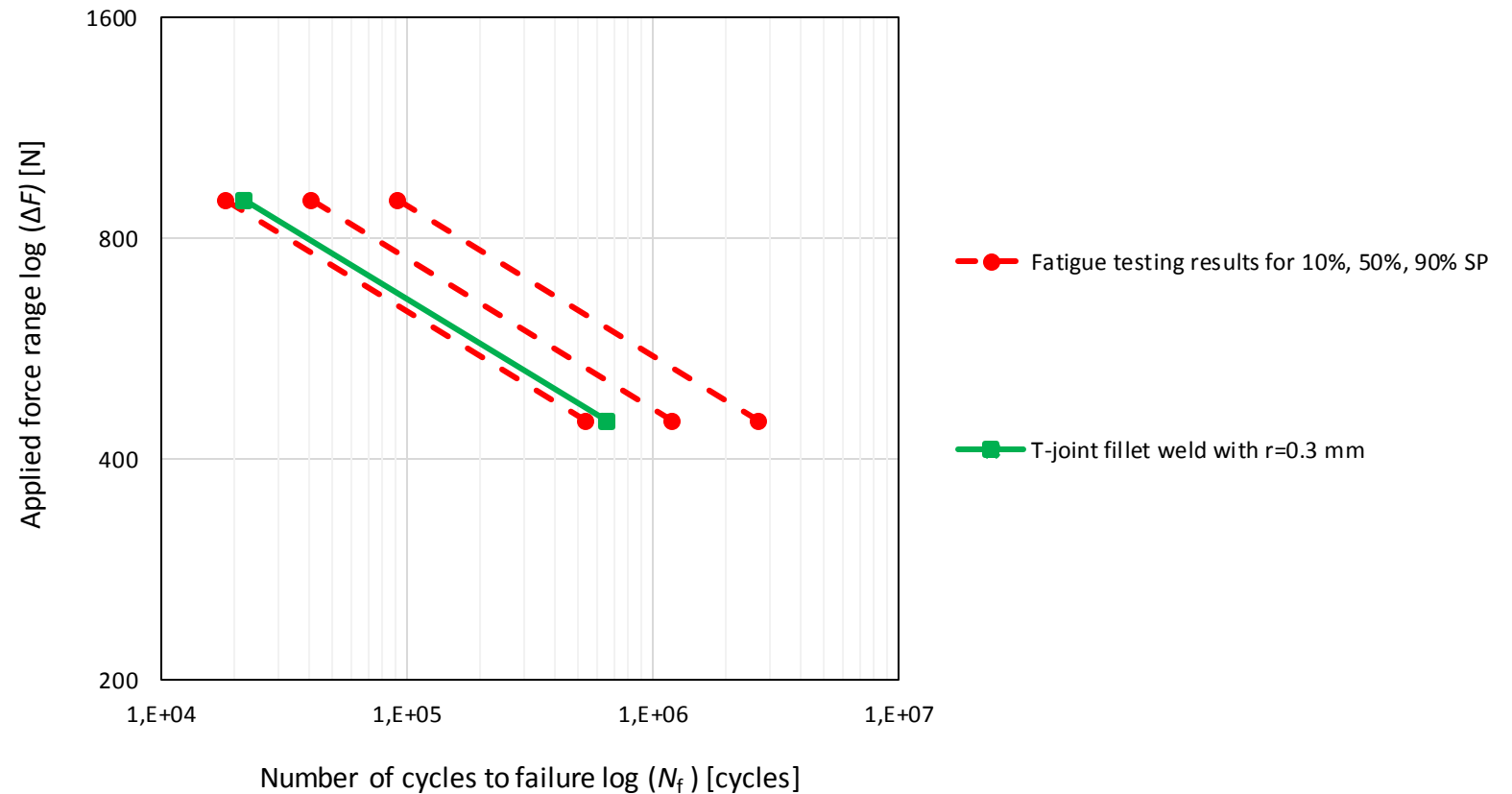
HCF testing and *FEMFAT Weld* results comparison

T-joint specimen – tension



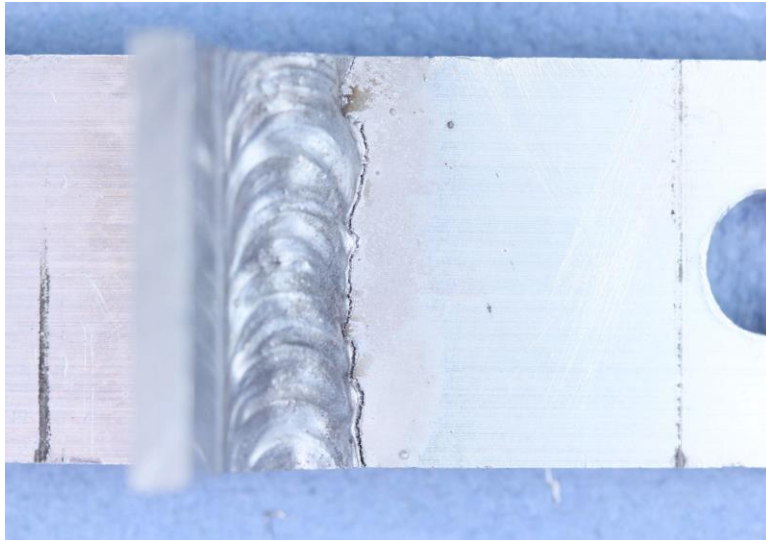
Crack initiation at the weld toe

- Assumption of $r = 0.3$ mm on the conservative side
- Further fine tuning of notch factors recommended



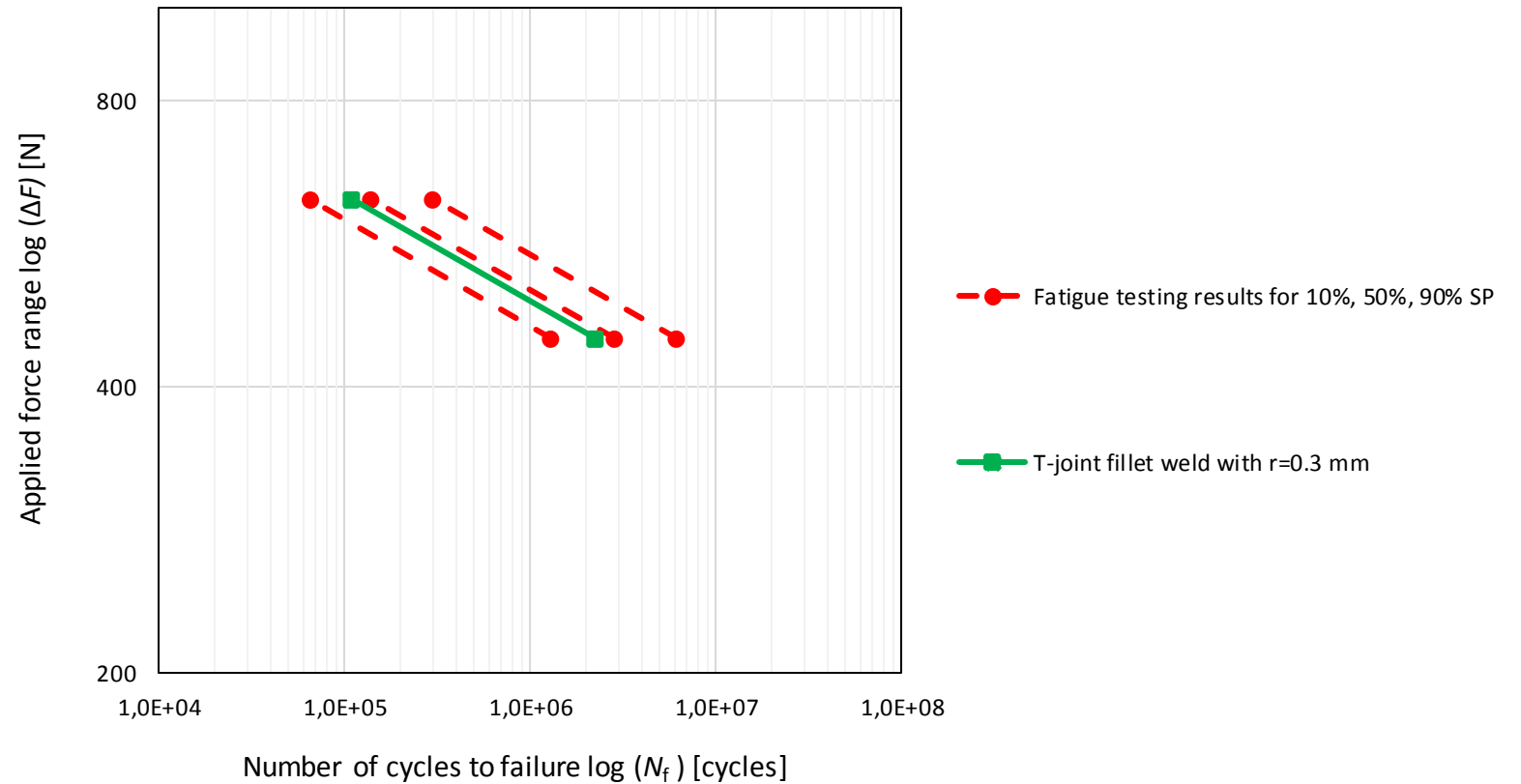
HCF testing and *FEMFAT Weld* results comparison

T-joint specimen – 3-point bending



Crack initiation at the weld toe

- Assumption of $r = 0.3$ mm correlated well



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Conclusions

- FEMFAT Weld
 - In general, good correlation with test results when FEMFAT modelling guidelines are followed.
- Fictitious notch radius for the modeling of the weld geometry:
 - Butt joint specimen
 - Assumption of $r = t / 10$ too conservative and not realistic because the measured weld radius varies from 1.0 mm onwards.
 - Recommended to use $r = 1.0$ mm.
 - T-joint specimen
 - Assumption of $r = t / 10$ gives reliable results since the measured weld radius varies in the range between 0.3 mm and 1.0 mm.

Thank you



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